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# REPORT ON SINGLE-STEP LINE-TYPE VOLTAGE REGULATOR

## A. INTRODUCTION

### 1. GENERAL

The need for equipment capable of correcting excessive voltage drop on rural distribution systems has been recognized in a previous report the use of a single-step line-type voltage regulator as one method of economical voltage regulation. Single-step voltage regulators were in operation on a distribution line in the State of Ohio from August 2, 1949, to August 2, 1950. During this period the regulators were in the manufacturer's laboratory for inspection. Operating experience was obtained from the manufacturer's laboratory for inspection. Operating experience was obtained from the manufacturer's laboratory for inspection. Operating experience was obtained from the manufacturer's laboratory for inspection.

The three designated experimental regulators were installed by October 1949; they have the following description:

Voltage Rating  
Voltage Regulated  
Number of Steps  
Capacity  
Manufacturer

1. General  
2. Scope  
B. SUMMARY  
C. THE TEST  
D. DISCUSSION  
E. FUTURE

It appeared desirable for RRA to participate in the development of the regulators on RRA-financed lines. Accordingly, an agreement was made between the Rural Electrification Administration, the Federal Power Commission, the Federal Bureau of Investigation, and the Rural Electrification Administration to conduct additional tests of the regulators on a single-phase line of the RRA. The Cooperative Extension Service furnished the distribution system facilities, pole line and cross arms, while RRA and the Company furnished the engineering personnel and instrumentation.

May 1950

## 2. SCOPE

This report discusses the results of tests of single-step line-type voltage regulators on rural distribution lines, installed on a single-phase line of the RRA.

Prepared By  
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Rural Electrification Administration  
United States Department of Agriculture  
Washington, D. C.

- a. The amount of voltage regulation required on a distribution line.
- b. Capability of the regulators to correct excessive voltage drop on a distribution line.
- c. The current action of single step voltage regulators on a distribution line.

Technical Report on Single-Step Line-Type Voltage Regulator, November 1950.

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## REPORT ON SINGLE-STEP LINE-TYPE VOLTAGE REGULATOR

### A. INTRODUCTION

#### 1. GENERAL

The need for equipment capable of more economically correcting excessive voltage drop on rural distribution systems has existed for many years. As discussed in a previous report† the use of a single-step line-type voltage regulator is being considered as one method of economically obtaining the desired results. Three single-step voltage regulators were in operation on a single-phase line undergoing tests, from June 15, 1949 to August 8, 1949. These regulators were then removed and returned to the manufacturer's laboratory for inspection. Operating experience and an examination of the regulators clearly showed the need for several changes. The previous report on the regulators contains a list of the changes that were considered desirable.†

The three redesigned experimental regulators were completed by October 1949; they have the following description:

Voltage Rating	7200 volts
Voltage Boost	5 percent
Number of Steps	One
Capacity	15 amperes
Manufacturer	Rural Transformer & Equipment Company

It appeared desirable for REA to participate in the field testing of the redesigned regulators on REA-financed lines. Accordingly, an agreement was made between the Rural Transformer & Equipment Company, the Oakdale Cooperative Electrical Association, and the Rural Electrification Administration to conduct additional tests of the regulators on a single-phase line of the Cooperative. The Cooperative furnished its distribution system facilities, pole line material and line crews, while REA and the Company furnished the engineering personnel and instrumentation.

#### 2. SCOPE

This report discusses single-step line-type voltage regulators as adapted to rural distribution lines, including the following:

- a. The amount of voltage boost for given system distribution voltage limits.
- b. Capability of the regulators to correct excessive voltage drop on a distribution line.
- c. The correct location of single step voltage regulators on a distribution line.

†Interim Report on Single-Step Line-Type Voltage Regulator, November 1949.

## B. SUMMARY

The important considerations in the use of single-step line-type voltage regulators on a distribution system may be summarized as follows:†

1. When using one regulator
  - a. The desired amount of voltage boost is six volts.
  - b. Six volts excessive voltage drop can be corrected.
  - c. The regulator should be located at a point where the voltage drop on the line is equal to eight volts.
2. When using two regulators cascaded
  - a. The desired amount of voltage boost per regulator is 4-1/2 volts.
  - b. A total of nine volts excessive voltage drop can be corrected.
  - c. One regulator should be located at a point where the voltage drop on the line is equal to eight volts, and the other regulator at a point where the voltage drop on the line is equal to 12-1/2 volts.
3. When using three regulators cascaded
  - a. The desired amount of voltage boost per regulator is three volts.
  - b. A total of nine volts excessive voltage drop can be corrected.
  - c. One regulator should be located at a point where the voltage drop on the line is equal to eight volts, the second regulator at a point where the voltage drop on the line is equal to 11 volts, and the third regulator at a point where the voltage drop on the line is equal to 14 volts.

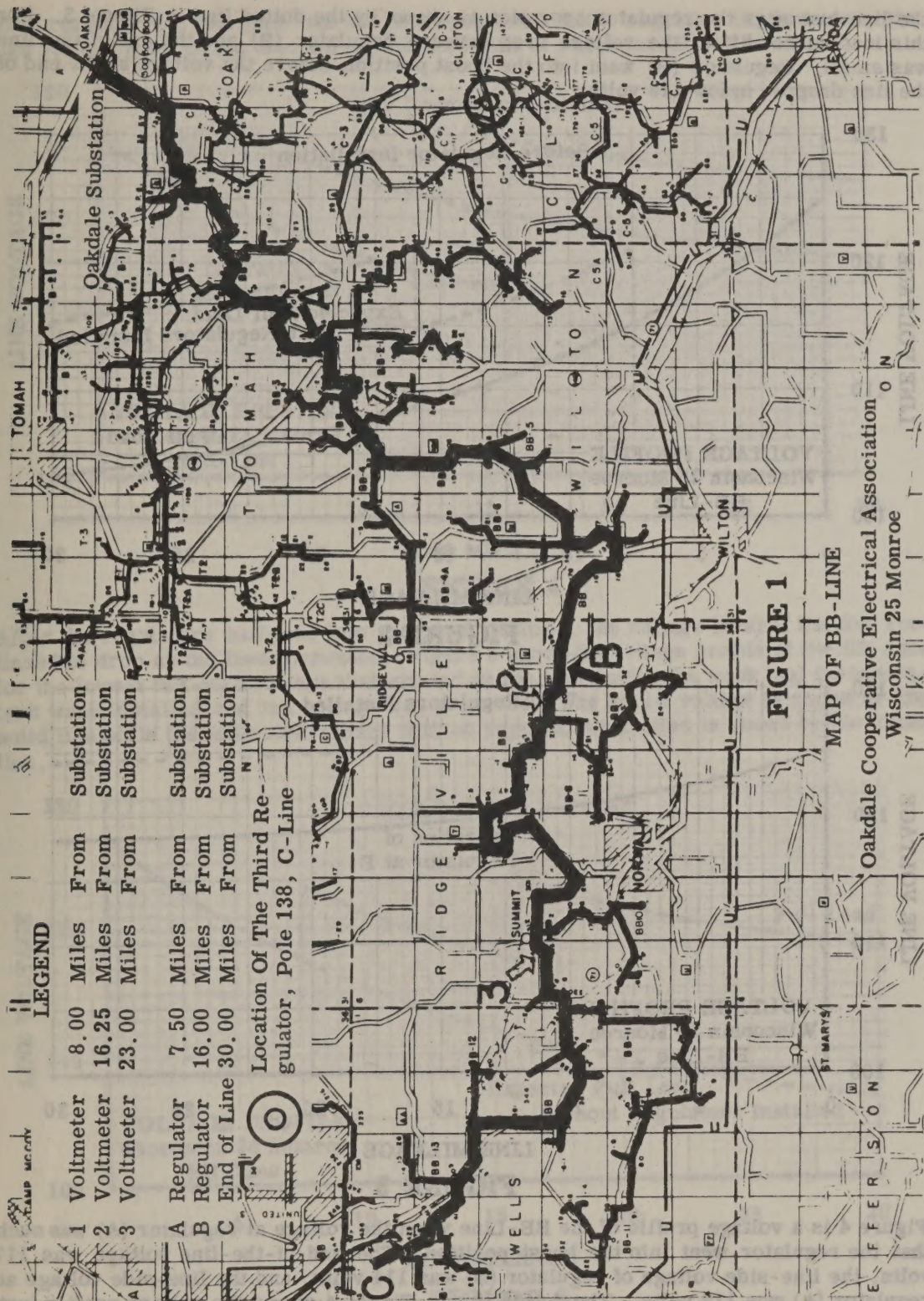
## C. THE TEST

Referring to Figure 1, the BB-Line and the T-2-Line were opened at point (C) in order to balance the load between the two lines. The voltage, current, and wattage of the BB-Line were recorded at the substation throughout the entire test. Voltages at three locations, (1), (2), & (3), as shown in Figure 1, were recorded for one week prior to the installations. The voltage regulator at the substation was adjusted to hold the output voltage variation of the substation between 124 volts and 127 volts during full load. The lowest full load voltage profile recorded during the first week is shown in Figure 2. The dotted portion of Figure 2 indicates the regulator locations based upon the predicted voltage profile.

After the regulators were installed, the recording volt-meters were moved from locations (1), (2), & (3) to the load side of regulators (A) & (B) and to the end of the line, (C) as shown on Figure 1. The voltages were recorded for one week while the regulators were in operation. In order to analyze the operation of the regulators, voltage profiles of the line were plotted for the various loading conditions which caused regulator operation. Figure 3 is a voltage profile of the BB-Line when the voltage at regulator (B) was such that the regulator went into the boost position. The voltage profile of

†For the purpose of discussion in this report, the voltage limits (referred to 120 volt base) on the distribution system are assumed to be as follows:

- Output of substation at full load--124 volts to 127 volts.
- Output of substation at light load--120 volts to 124 volts.
- Voltage on distribution line--116 volts to 127 volts.
- Voltage drop on distribution line--8 volts maximum.



the line just after the regulator operation is shown by the dotted line in Figure 3. For this loading condition, the voltage drop between regulator (B) and the end of the line was small. Regulator (B) went into the boost position before the voltage at the end of the line dropped below 118 volts.

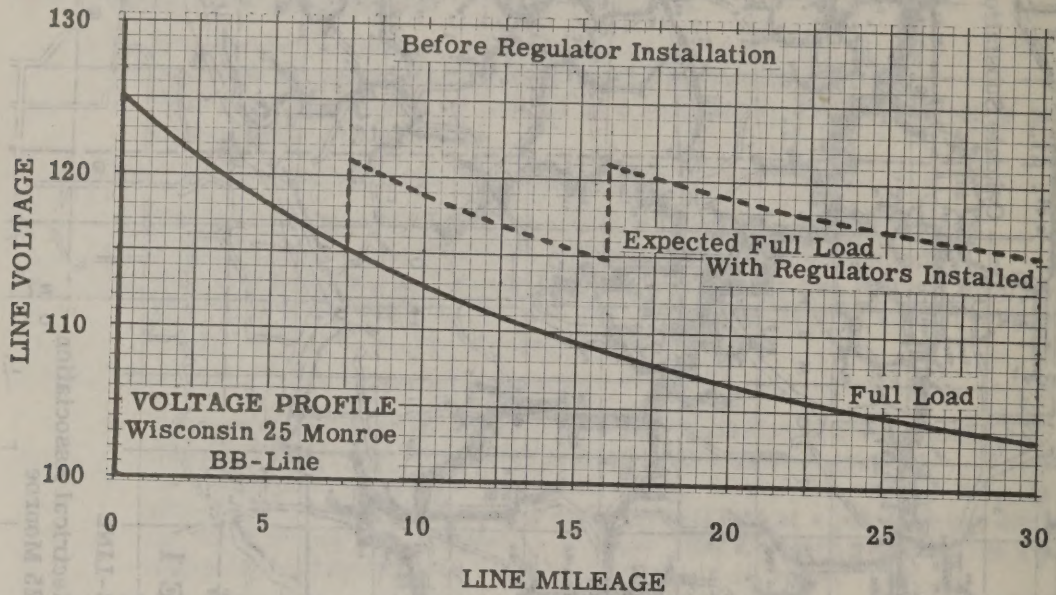


FIGURE 2

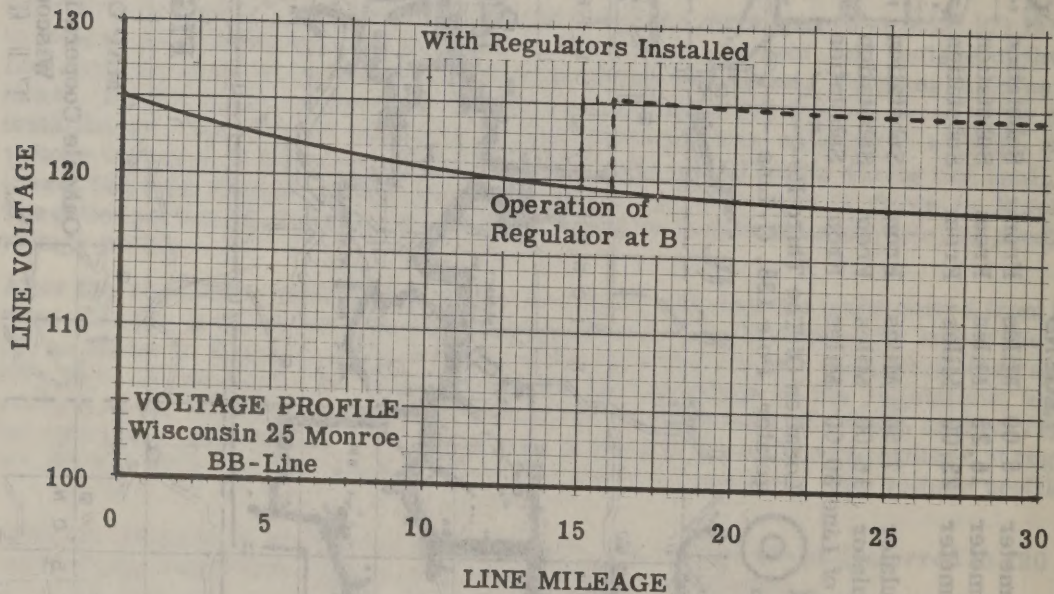


FIGURE 3

Figure 4 is a voltage profile of the BB-Line when the voltage at regulator (A) was such that the regulator went into the boost position. The end-of-the-line voltage was 117 volts, the line-side voltage of regulator (B) was 114 volts, and the line-side voltage at regulator (A) was 119 volts. The dotted line in Figure 4 shows the voltage profile just

after regulator (A) had gone into the boost position. After regulator (A) operated, the high voltage point on the line was at the load-side of regulator (B), 126 volts.

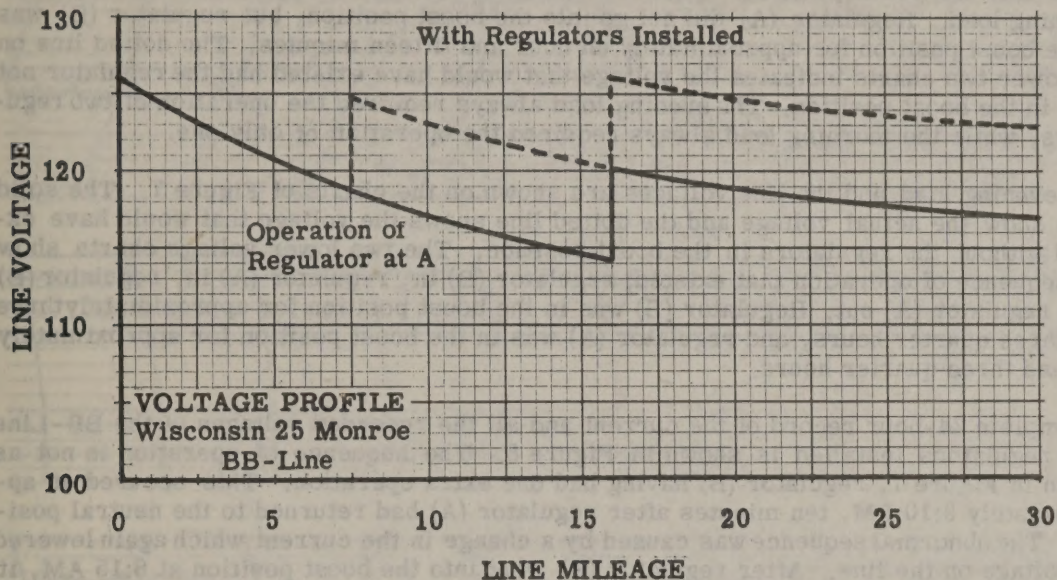


FIGURE 4

After the regulators had gone into the boost position, the voltage level of the line continued to drop as the load increased. Figure 5 shows the voltage profile of the BB-Line for the lowest full-load voltage that existed on the line during the week that the regulators were installed and the voltage was recorded. The actual voltage is shown by the solid line while the estimated voltage without regulators installed is shown by the dotted line.

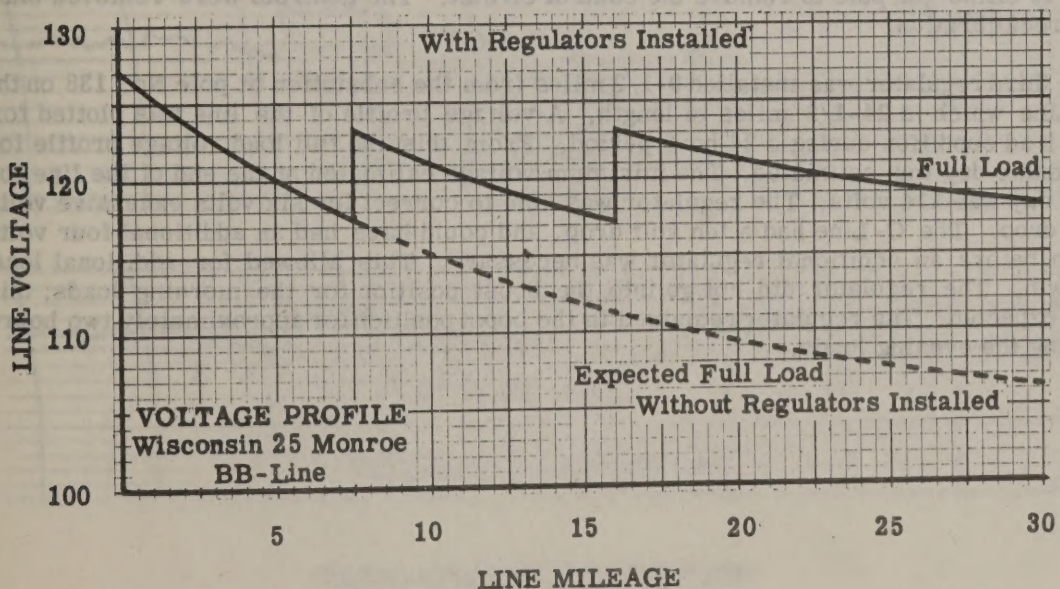


FIGURE 5

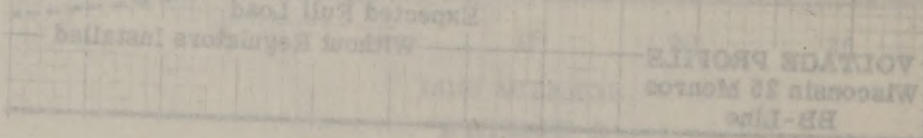
The load cycle of the line did not always require that both regulators go into the boost position. For example, the morning load on the BB-Line required only regulator (B) to go into the boost position. Figure 6 contains a portion of the charts that show the morning load. Regulator (A) did not go into the boost position, but regulator (B) was in the boost position for approximately an hour and fifteen minutes. The dotted line on the lower two charts indicates the voltage that would have existed had the regulator not been in the boost position. The evening load always required the operation of two regulators, while the morning load always required the operation of only one.

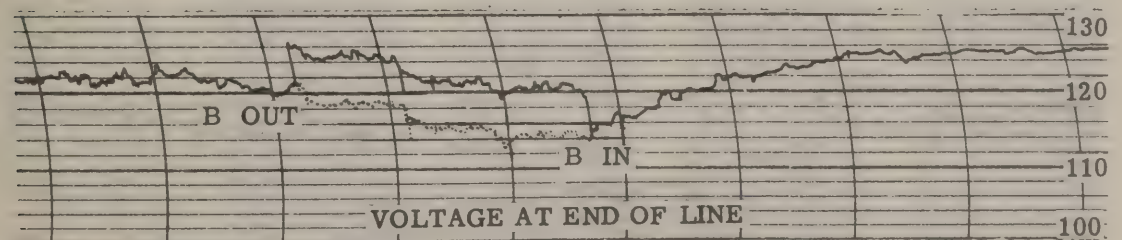
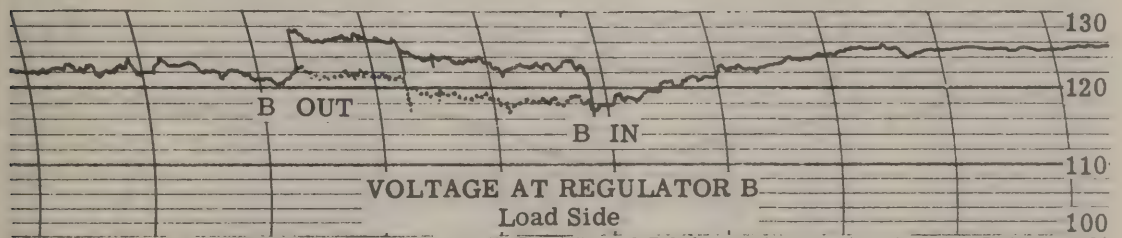
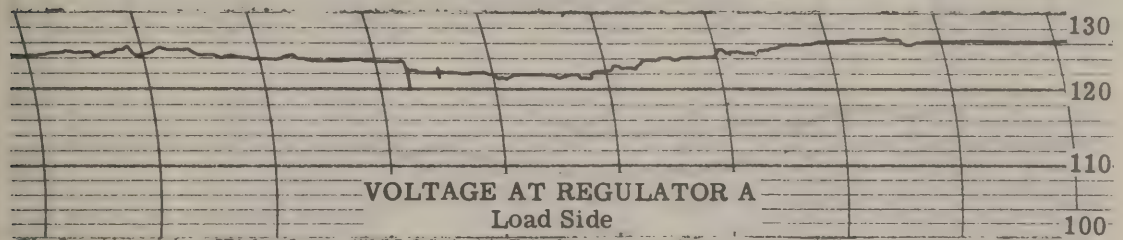
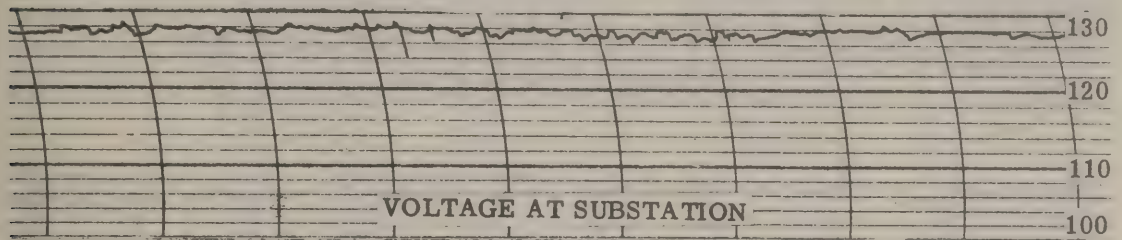
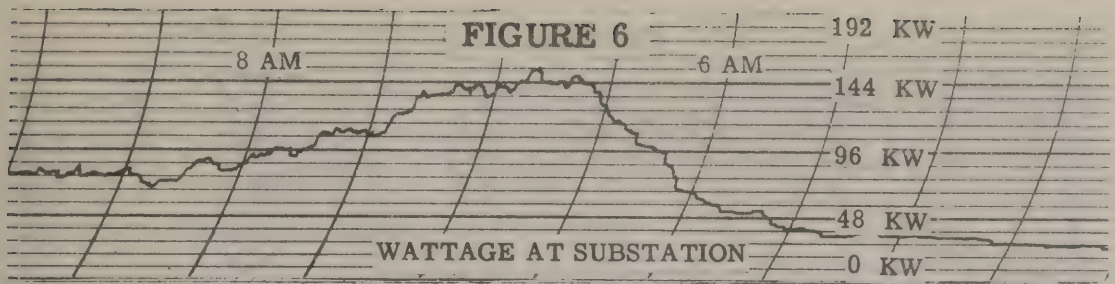
The evening load and the line voltages are shown on the charts of Figure 7. The solid lines show the actual voltage and the dotted line shows the voltage that would have existed without the regulators in the boost position. The two lower voltage charts show the sequence of operation that existed; regulator (B) in, regulator (A) in, regulator (B) out, regulator (A) out. Regulator (B) was in the boost position for approximately three and three quarter hours, and regulator (A) was in the boost position for approximately one and three quarter hours.

A complete 24-hour record of the current and all the recorded voltages of the BB-Line with regulators installed is shown in Figure 8. The sequence of operation is not as shown in Figure 7, regulator (B) having had one extra operation. This occurred at approximately 8:10 PM, ten minutes after regulator (A) had returned to the neutral position. The abnormal sequence was caused by a change in the current which again lowered the voltage on the line. After regulator (B) went into the boost position at 6:15 AM, it remained in the boost position until 1:45 PM. The morning load shows the application of one regulator on a line not needing more than a 6-volt boost, and the evening load shows the use of two regulators on a line. Consumers at the end of the line were subjected to eight changes in voltage during a 24-hour period. The consumers never were subjected to more than one voltage change within a 10-minute period.

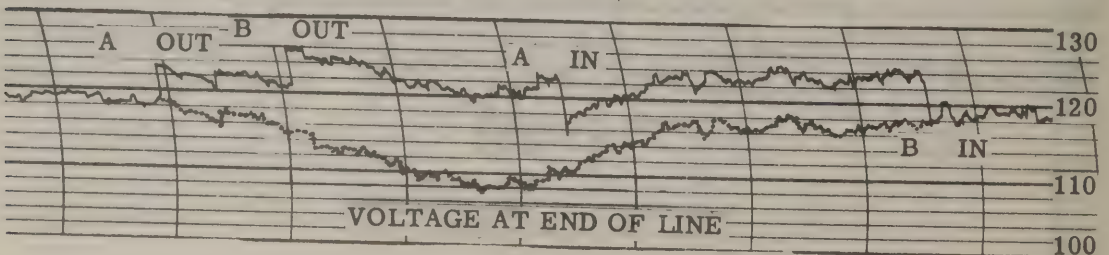
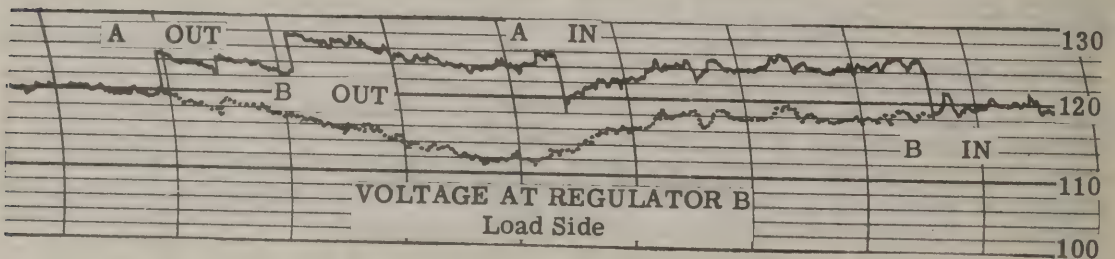
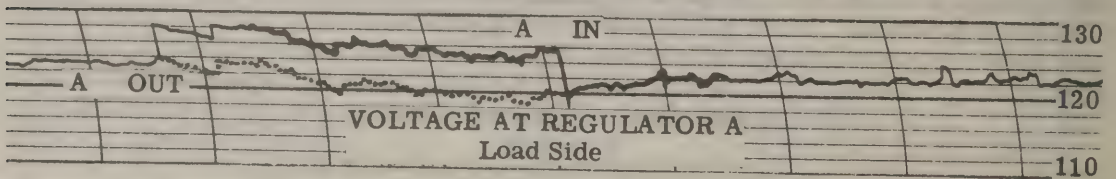
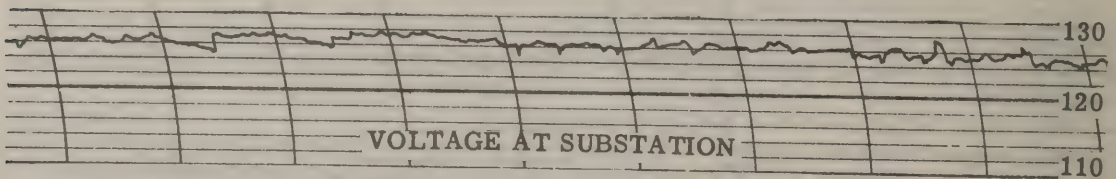
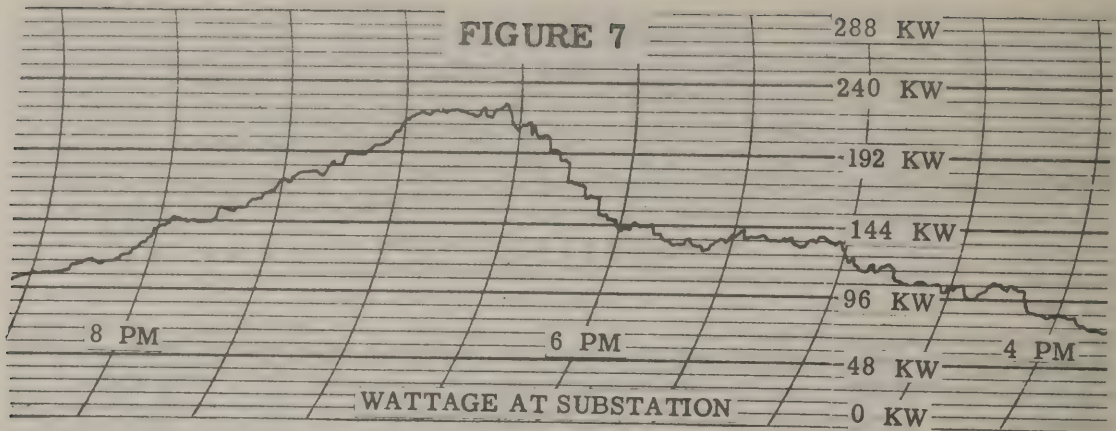
Figure 9, 10, & 11 are photographs of the temporary installations. The control housing was made an integral part of the main tank. With the construction used it was necessary to climb the pole to remove the control circuit. The controls were removed once for recalibration.

The third regulator was installed 9-1/2 miles from the substation at pole No. 138 on the C-Line which is 24-1/2 miles in length. A voltage profile of the line was plotted for one load condition during a 24 hour period. From this the full load voltage profile for the same day was estimated. The minimum voltage estimated at the end of the line for that day was 114 volts. The regulator was able to correct for six volts excessive voltage drop. The C-Line had a ten volt drop, and could have had an additional four volts drop before an additional regulator was necessary. This allowed for additional load growth. The regulator did not go into the boost position for the morning loads; this was expected. The regulator remained in the boost position for approximately two hours during the evening loads.





**REGULATOR VOLTAGE CHARTS**  
BB-Line Wisconsin 25 Monroe

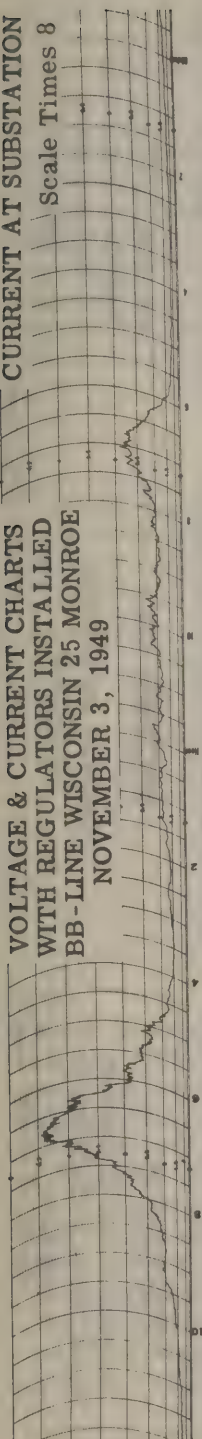


**REGULATOR VOLTAGE CHARTS**  
BB-Line Wisconsin 25 Monroe

VOLTAGE & CURRENT CHARTS  
WITH REGULATORS INSTALLED  
BB-LINE WISCONSIN 25 MONROE  
NOVEMBER 3, 1949

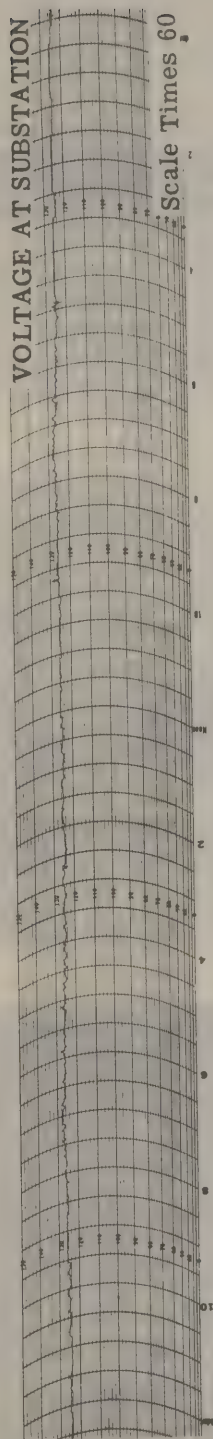
CURRENT AT SUBSTATION

Scale Times 8



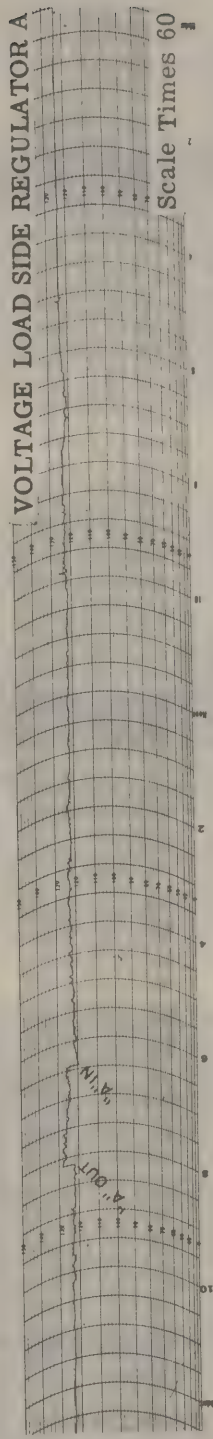
VOLTAGE AT SUBSTATION

Scale Times 60



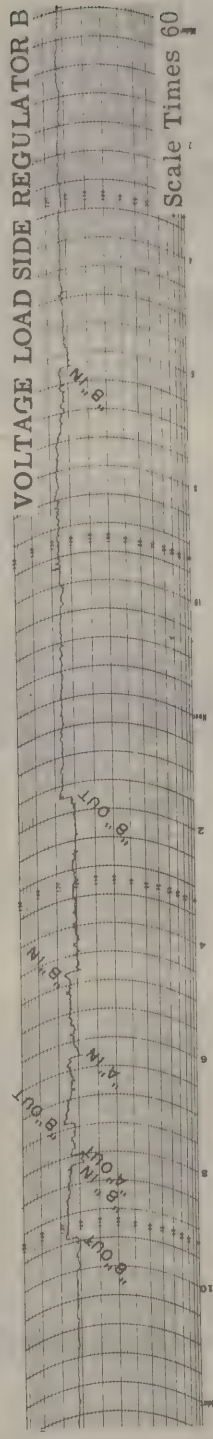
VOLTAGE LOAD SIDE REGULATOR A

Scale Times 60



VOLTAGE LOAD SIDE REGULATOR B

Scale Times 60



VOLTAGE AT END OF BB-LINE

Scale Times 60

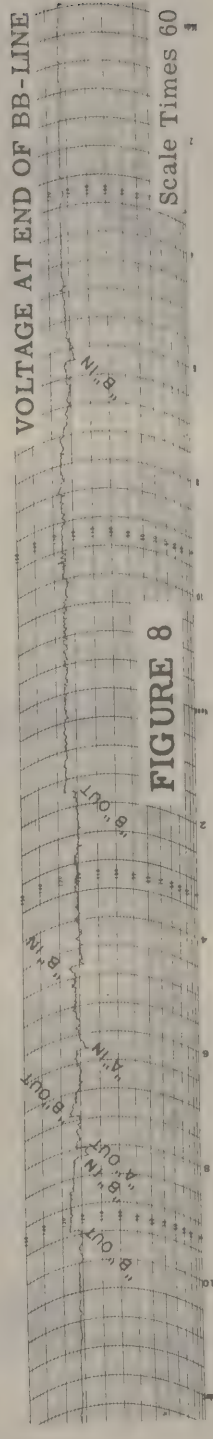


FIGURE 8



**FIGURE 9**  
Regulator And Voltmeter  
Installation At Location A  
BB-Line



**FIGURE 10**  
Regulator Installation  
On C-Line



**FIGURE 11**  
Regulator Installation  
At Location B  
BB-Line

## D. DISCUSSION

From the data presented above, it is evident that single-step line-type regulators can be operated successfully. However, a more detailed study of all the aspects should be made before general acceptance of the practice can be given.

When single-step line-type regulators are used on a line, they must be capable of correcting the excessive voltage drop without allowing the voltage at any point on the line to exceed design limits. The capability of the regulators to perform this function depends upon their location, amount of voltage boost per regulator, control settings, and the number used on a line. The amount of voltage boost per regulator is dependent upon the number of regulator used and upon the voltage limits. The control settings for raising and lowering the voltage is dependent upon the number of regulators used, upon the amount of boost per regulator, and upon the voltage limits. The following table shows the correct relationships for proper performance:

SINGLE-STEP LINE-TYPE VOLTAGE REGULATOR APPLICATION  
(Voltage At Any Point On Line - 116 to 127 Volts)

ACTUAL VOLTAGE DROP ON THE LINE	ALLOWABLE VOLTAGE DROP ON THE LINE	NUMBER OF REGULATORS REQUIRED	VOLTAGE BOOST PER REGULATOR	VOLTAGE DROP SUBSTATION TO REGULATOR	CORRECTED EXCESSIVE VOLTAGE DROP	NET VOLTAGE DROP SUBSTATION TO END OF LINE	TO-RAISE VOLTAGE *	TO-LOWER VOLTAGE **
8	8	0	---	---	---	8	---	---
14	8	1	6	8	6	8	119	127
17	8	2	4½	NO. 1 - 8 NO. 2 - 12½	9	8	120	127
17	8	3	3	NO. 1 - 8 NO. 2 - 11 NO. 3 - 14	9	8	121	127

\* To-Raise Voltage --The voltage at which the regulators should raise the line voltage.

\*\* To-Lower Voltage --The voltage at which the regulators should lower the line voltage.

When the end-of-the-line voltage drops below 116 volts, one regulator should be installed. The table specified that the amount of boost needed is 6 volts. The regulator should go into the boost position before the end-of-the-line voltage goes below 116 volts. Immediately after the regulator boost operation, the regulator load-side voltage should not be above 127 volts. The voltage at which the regulator should be set to lower the voltage is 127 volts. Due to the voltage variations existing on the line, the value at which the voltage is boosted and the value at which the voltage is lowered should not be the same. The variations are caused by the substation voltage regulator band width. The recommended band width for substation regulators is two volts. When allowance is made for the two volts, the maximum voltage on the load-side of the regulator after the boost operation should be 125 volts. The voltage at which the regulator should go into the boost position should not be less than 119 volts in order that the end-of-the-line voltage does not drop below 116 volts.

When the end-of-the-line voltage, with the aid of one regulator, drops below 116 volts two regulators should be installed. When two regulators are cascaded on a line, the maximum amount of voltage boost per regulator is determined from the allowable vol-

tage limits on the line. For maximum and minimum limits of from 116 volts to 127 volts, the maximum amount of boost per regulator when cascading two regulators is one half the difference, or 5-1/2 volts. The first regulator from the substation should be set to boost the voltage before the line-side voltage of the second regulator drops below 116 volts. For this condition, the load-side voltage of the second regulator will equal 116 volts plus the sum of the voltage boosts of the regulators. Should the maximum amount of voltage boost be used, there would not be the desired voltage difference between the load side voltage of the second regulator and the maximum line voltage. When allowance is made for the two volt band width of the substation regulator, the desired voltage boost per regulator for two cascaded regulators becomes 4-1/2 volts. The voltage at which the regulators go into the boost position should be not less than 120 volts in order that the line-side voltage of the second regulator does not drop below 116 volts.

Since three regulators do not correct more excessive voltage drop than do two regulators, the installation of three regulators is neither practical nor economical.

## E. FUTURE

Information concerning the use of single-step line-type voltage regulators will be included in a REA publication on voltage regulators and voltage regulation problems, including the following points:

1. Method of obtaining a voltage profile of a distribution line.
2. Use of voltage profiles to locate correctly line-type voltage regulators.
3. Proper operation of line-type voltage regulators.

Any additional single-step line-type voltage regulators will be placed in service on a test basis until they prove completely satisfactory for use on rural distribution lines.



